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METHODS OF SOIL STERILIZATION FOR PLANT BEDS AND GREENHOUSES

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There is urgent need for practical methods of steam sterilization which can be applied to hot-beds and cold-frames, as well as to greenhouse soils. Since the publication of Circular No. 57 in 1906 there has been increasing calls for directions for methods of plant bed treatment to kill out soil infesting organisms. These methods, as developed, are essentially three in number; involving, first, the perforated pipe method of steam sterilization; second, the inverted pan method, using steam; and third, the formaldehyde or formalin drench method. It will be noted that the first two are different adaptations for applying steam, developed according to the needs of those who are located, like the greenhousemen, near a large boiler plant, or for those who are remote from such steam supply and must therefore utilize more portable, and possibly even more readily adjustable, methods of soil steaming.

The first and third methods, namely: sterilization by the use of steam applied through perforated pipes and by formaldehyde drench have been briefly described in Circular No. 57. The inverted pan method, which appears to have a very large usefulness for the treatment of soils in hot-beds, cold-frames and outdoor plant beds, generally, was originated by A. D. Shamel, of the Bureau of Plant Industry, United States Department of Agriculture, and has many apparent advantages for the trucker or tobacco grower who wishes to use steam for that purpose.

THE PERFORATED PIPE METHOD

The perforated pipe method of steaming appears to consist, at its best, in a system or set of perforated pipes, with crosshead and high pressure boiler connection. These pipes are connected and

buried in the soil of the bed, either with or without partial banking up of the soil; the surface of the bed is then covered with canvas or other covering and the steam passed into the system for such a period as is required to heat the soil to the necessary temperature. This temperature for best results is 180° to 212° Fahr. maintained for a period of an hour or more. The time required to reach this temperature will vary with the boiler area, the pressure and other steam and soil factors. The length of pipes of the system will be adapted to the beds, being one-half or one-third the total length of large beds. Generally, 1½ inch pipe is used with ⅛ inch holes bored in a straight line about 1 foot apart. These pipes are buried in the beds 12 to 16 inches apart. The crossheads and main to boiler should be 2 inch pipe or larger.

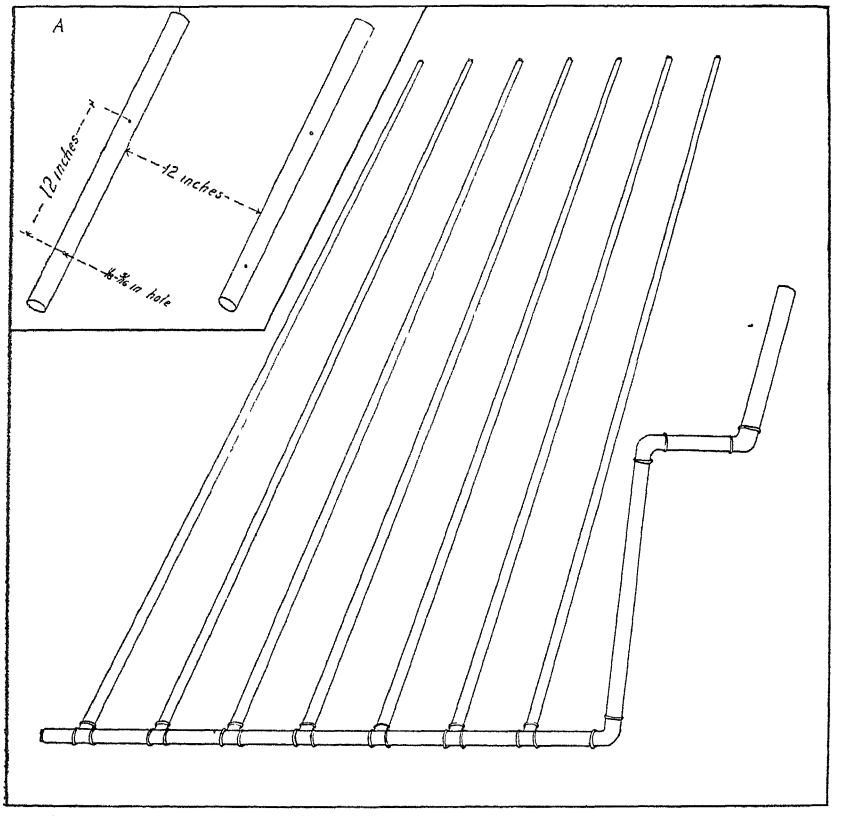

Fig. 1. Diagram of system of perforated pipes, showing 7 parallels of 1 1-2 in. pipe 40 ft. long; crosshead of 2 in. pipe; and connections to steam main, 2 in. pipe or larger; each pipe joined to crosshead with T connections. Insert Cut "A" shows relative spacing of pipes with size and spacing of holes. These are recommended to be 1-8 in. or 3-16 in. diameter, placed 12 inches apart on under side of pipes.

Details of Construction and Cost: The size of pipes which has been found to be most serviceable is, for those buried, 1½ inch.; the crosshead and steam main should be of 2 in. pipe or larger, the reducing T connections and elbow joints secured accordingly.

The diagramatic illustration (Fig. 1) shows the arrangement of the pipes in place. The corner figure A gives relative size of parallel pipes and their distance apart, which may be from 12 to 16 inches. The holes may be either 1-8 inch or 3-16 inch, placed from 12 to 15 inches apart and in position should face downward.

The number and length of pipes used must conform to boiler capacity and length of beds. In general, the perforated pipes should not be more than 40 feet in length nor exceed 7 or 8 in number; pipes 30 feet in length will be found to be most serviceable with medium boiler capacity, say 50-60 H. P. For 100 H. P. boilers and above the number and length of pipes per bed may be somewhat increased.

In burying the pipes it is well to see that they lie level in the bed, so that condensed steam does not accumulate at any one point; the pipes should be buried to a depth of 4 to 6 inches and evenly covered over with the soil. Canvas, burlap, or carpet may be spread over the surface to be sterilized, thus preventing the ready escape of steam.

In practice it is found that to make the best use of fuel and labor, two sets of perforated pipes are needed. Estimating 8 pipes to a bed and 30 feet long, 240 feet of pipe will be required for one set; and two sets with crosshead pipe will require about 500 feet of pipe. Pipe such as required, 1½ in. in diameter, can be bought as low as two cents per foot from building and wrecking companies, while new 1½ in. pipe can be bought for 4 cents per foot. Estimating the pipe at 3 cents per foot for 500 feet, with connections, crosshead, cost of drilling holes, and fitting, at $6.00, the initial cost of two perforated pipe systems will be on an average about $20.00, or $10.00 for each one.

The two sets of pipes are suggested in order to save outlay for labor and fuel. It requires time to dig up and reset a system of pipes, and this resetting of one system may be done while the process of steaming is going on in the other system; thus no labor is idle and steam will not have to be kept up unnecessarily long. In fact, the double system reduces fuel and labor by nearly one-half that required where only one system of pipes is used.

THE INVERTED PAN METHOD

As originally devised by Shamel to treat nematode-infested soils in Florida, the inverted pan is adapted to being lifted and transported, where the distances are not too great. W. W. Gilbert* has described and illustrated the type of pan used to sterilize tobacco beds in Connecticut where root-rot prevailed. His statement is as follows:

"The apparatus consists of a galvanized iron pan, 6 inches deep and 6 by 10 feet in size, which is inverted over the soil to be sterilized and the steam admitted under pressure. The pan is supplied with steam hose connections, has sharp edges, which are forced into the soil on all sides to prevent the escape of steam, and is fitted with handles for moving it from place to place, the weight of the entire pan being not over 400 pounds."

"The soil is prepared as in the greenhouse method, a few potatoes being buried at a depth of a foot to guage the degree of heat obtained. A soil thermometer may also be used if desired. The steam should be kept at as high pressure as possible, 80 to 100 pounds being best, and the treatment should continue for one or two hours, depending on the pressure maintained. In the experiments conducted in the spring of 1907, one hour's steaming at 80° C. under 100 pounds pressure gave best results in killing both the fungus and the weed seeds. When one section of the bed is treated the pan is lifted and carried to an unsterilized portion and the operation repeated until the entire bed is steamed."

Details of Construction and Cost: Material used for construction of pan is galvanized sheet iron; the most useful weight is No. 20 guage, which weighs 26.5 ounces per square foot, or possibly No. 22 guage, weighing 22.5 ounces per square foot. The heavier material requires little in the way of frame supports. The galvanized iron sheets come in sizes varying from 2 to 3 feet in width by 8 to 10 feet in length. The illustration, Figure 2, shows a pan 6x10 feet in size, 6 inches deep, constructed from 5 such strips, 2½x8 feet in size. These sheets are joined by double fold seam and riveted at intervals of 6 to 10 inches to make the pan steam tight. The pan is further strengthened by a band of strap iron, 2x⅛ in. riveted to the bottom edge, and stiffened by a brace of 1¼ in. angle iron across the top and extending down the sides; this is bolted at

*Bul. Bur. Pl. Ind., U. S. D. A. 158:35-36, pl. V., 1909.

the sides to the supporting strap iron stiffener. The corner illustrations show at "A" the joint used for the galvanized iron sheets, and "B" a section of the angle iron supporting the top.

The entrance pipe for the steam may be placed at the side or end of the pan (see dotted construction lines of cut) or may enter from the top as per illustration. The latter form has the advantage in that it will not interfere with the box boards when used on frames; however, the pipe after entrance should be a T-form so that steam in being forced into the pan when in place does not "blow" holes in the soil.

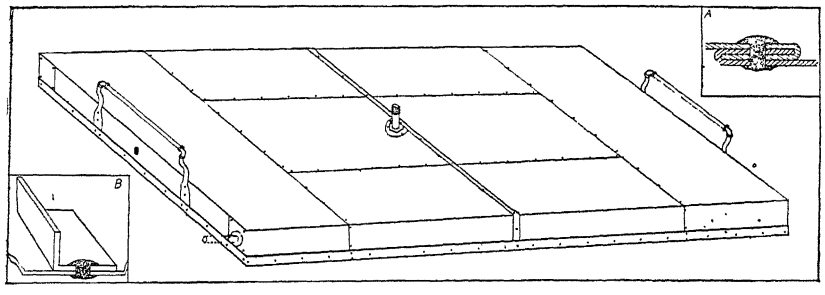

Fig. 2. The above drawing illustrates an inverted pan 6x10 ft. by 6 in. deep, made of 5 strips of galvanized iron with nipple for hose attachment to admit steam at top; construction lines at end indicate where steam is sometimes admitted. The inlet always to terminate in T form for dispersal of steam. The lower rim is stiffened by a continuous strap of 2 in. by 1-8 in. iron riveted to the lower edge of the pan. At ends are shown handles riveted to this stiffener and projecting above the top of the pan. Where this projection is objectionable iron pipe handles may be used with nipple base attached in the usual manner. Weight of such a pan probably less than 200 lbs.

Insert "A" shows details of folded double seam joint used in connecting the sheet iron.

Insert "B" gives details of attachment of angle iron across middle of pan; at each side this angle iron is bent over and bolted or riveted to the iron strap above described as facing the lower edge of the pan.

For the most economical use of fuel and labor in the pan method of steaming, three or possibly four pans will be necessary, according to width of beds. Estimating the cost of the pans at $15.00 apiece, the first outlay will be about $50.00 for set of three pans and connections.

The nature of the connections required will be determined by experience and by the location of permanent boilers or drives along which the mounted boiler may be hauled. With steam up each pan is lifted and re-set at intervals, so that with the three pan system there is a minimum loss of time in the transaction, as well as a minimum waste of energy through unused steam. In fact, it is expected to be using two pans continuously so that the loss is kept very low.

In setting a pan, the rim is sunk into the soil to a depth of three or four inches to make the inclosed chamber steam tight; trenching may be necessary at times when working in heavy soils. When steam at high pressure (50 pounds or more) is admitted, the pan may need to be weighted down unless it is constructed of the very heaviest material. In steaming out-door beds and cold frames, where it is necessary to make use of a traction engine or portable boiler of rather limited capacity, the 10 to 12 H. P. boiler will furnish steam for one pan only. The size of such pan may properly be about 6x8 ft. or its equivalent in area. Width or length of the pan in all cases is best made to correspond to the dimensions of the beds. Where beds are about six feet in width, the width of the pan may properly be the same. Where, for any reason, the beds are very wide the length of the pan may be made to correspond to the width of the bed if found desirable to do so. Further details in practice will be found under individual reports.

Steam Rake Method: A method of sterilization by use of the steam rake, in which steam is admitted to the soil through perforations in a movable, rake-like apparatus, has not proved successful in practice, according to Gilbert. The difficulty is that the steam, instead of permeating the soil, quickly pushes its way up through the finely pulverized soil, and hence has little value in soil heating.

FORMALDEHYDE (FORMALIN) DRENCH METHOD

Soils to be treated by any method of sterilization should be prepared as for use by addition of manure so that the latter is incorporated with the soil before treatment. The soil after spading or plowing is ready for treatment, whether by steaming or drenching. For the work of drenching it is rather difficult to make exact estimates as to cost of appliances, as well as labor outlay, since the appliances are the usual watering devices of greenhouses or cold frames, and the labor will be somewhat variable according to the effectiveness of these devices. The appliances used may be extremely various, though usually some form of sprinkling can, a force pump with hose and nozzles or application through the overhead Skinner watering system. For outside beds the hose and force pump offer a convenient method. Naturally the cost items in the drench method become reduced almost to that of cost of material. The best strength appears to be 3 to 3½ pints or pounds to each 50 galons of drench, applied at the rate of ⅞ to 1 gallon per square foot of surface. Estimating that Formaldehyde (U. S. P. 40%) costs 80 cents per gallon, and that a strength of approximately 1 to 125 (3½ pints or pounds of formaldehyde to 50 gallons of water) be used at the rate

of 1 gallon of the solution to each square foot of area, the material to treat one house 30x100 ft. (3,000 sq. ft.) amounts to approximately $21.00.

RELATIVE OPERATION COSTS OF DIFFERENT METHODS

Estimating that pans and pipes last five years, that labor costs $2.00 per day, coal $3.50 per ton, and that ten houses are sterilized every year, it will cost to treat one house 30x100 feet (3,000 sq. ft. in area) approximately as follows:

By Perforated Pipe Method:

Charge for depreciation of system per house per year	$ .40
Fuel, 2 tons coal at $3.50 per ton	7.00
Labor, 2 men 2 days	8.00
Total (3,000 sq. ft.)	$15.40

By Inverted Pan Method:

Charge for depreciation of pans per house per year	$ 1.20
Fuel, 2 tons coal at $3.50 per ton	7.00
Labor, 2 men 1 day	4.00
Total (3,000 sq. ft.)	$12.20

By Formaldehyde Drench Method:

Material only to drench 1 house (3,000 sq. ft.)	$21.00

NOTES AND REPORTS ON STERILIZING

Practice in soil sterilization varies and must necessarily do so owing to varied conditions in greenhouse structure, heating apparatus, etc., and to a still greater extent to the kinds of soil used in greenhouses and outside beds. In general, a sandy soil will require less time to be thoroughly heated to the desired depth than will a silt-loam soil or one of heavier clay.

Water conditions of the soil when treated with steam influence greatly the effectiveness of such treatment, and also the results of steaming; a dry soil, and particularly one containing a high percent of humus, will be very apt to suffer some injury, especially in that portion next to the steam pipes. Light soils, and those rich in humus, would better be steam treated with the pan method. Again, soil thoroughly wetted will be extremely slow to heat up. In practice, soil should be wetted to the extent of a little less than good growing conditions when steamed either by pipes or by the pan method; this condition will generally be found satisfactory in using the formaldehyde drench. With the proper precautions following treatment in the way of watering and in stirring up the soil, it is

very unlikely that any type of soil will fail to respond beneficially, whether the method used is perforated pipes, inverted pan or formalin drench. Various experiments in soil treatment have frequently given poor results for the first crop, but succeeding crops on sterilized soils have invariably given better results than on untreated soils. This appears to apply more especially to heavy soils which undergo certain changes of water relations as a result of steaming. Great caution must be observed that a recently steamed soil is not over-watered, thus giving it the water-logged structure which prohibits or greatly retards growth of plants.

The frequency necessary in sterilizing soils will also vary from time to time and with localities which have different types of soil.

Rotation of crops will, of course, minimize the need of soil treatment, but where one crop follows itself continuously, the soil is certain to harbor more and more fungi and will finally need some treatment. Greenhouse seed beds commonly will need treatment more often than transplant beds. Certain growers make a practice of sterilizing once a year, while others sterilize once in two or three years.

Beds treated with formaldehyde (3 pints to 50 gallons of water or stronger) should be stirred every few days to rid the soil of fumes poisonous to young plants; and such beds should not be seeded or planted for a period of 10 days after the drench is applied.

INDIVIDUAL PRACTICES

Mr. M. L. Ruetenik, of Cleveland, Ohio, uses four inverted pans 7½x8 feet. These pans cover the width of a 30 ft. house, and 12 shifts of this tier of pans covers one house 100 feet long. Two men will thus steam one house per day, each area being steamed from ¾ to 1 hour with steam at 30 pounds pressure from a 100 H. P. boiler. He alternates the pan method of steaming with the formalin drench, using 3 pints to 50 gallons of water, and one gallon of the solution per square foot of bed space. This method has given him the best results, in that the soil is relieved from too frequent steaming. This alternating of sterilizing practice would seem to be well adapted to many greenhouse soils, and results from further experiments along this line will undoubtedly emphasize this method of treatment.

Mr. C. A. Hooper, of Cleveland, Ohio, uses pans 6x8 feet by 10 inches deep, made of No. 24 guage galvanized sheet iron, each pan weighing about 100 pounds. Each area is steamed one hour with steam at pressure of 40 to 70 pounds.

Mr. E. A. Dunbar, of Dunbar & Hopkins, Ashtabula, Ohio, under date of December 3, 1914, writes as follows:

"Regarding your letter of the 2d inst. Our investigation of the methods of other greenhousemen regarding the sterilizing proposition has not converted us to any other method. It is still our conviction that if it pays to sterilize, or if it is necessary, the job should be done thoroughly, if at all. To this end we have chosen our pipe method in preference to anything else we have seen. We are about to begin the sterilization of our tomato houses, the crop having matured very rapidly, due to the continued warm weather. We shall use in one setting nine 1½ in. pipes, 15 inches apart, 70 ft. long, with ⅛ in. holes 1 ft. apart, 80 pounds steam pressure on 300 h. p. boiler for one hour at a setting. I am unable today to give you the temperature of the soil reached, but will say on the side that the particular area has, during the growth of the tomato crop, become badly infested with nematodes, otherwise we would consider 45 minutes sufficient for the heat to run, but we must kill out this trouble, if possible."

Messrs. Searles Brothers, of Toledo, Ohio, under date of December 4, 1914, write as follows:

"Your letter of December 2d at hand and will try to answer a few of your questions. We sterilize each year with steam. We use the perforated pipes altogether, a machine made by us some years ago. We used the pan one year and discarded it. The perforations in the steam pipes should not be more than 3-16 in., but of course, it depends upon the volume of steam delivered to your pipes.

"Our steam leaves our boiler under a pressure of from 85 to 90 pounds, and we leave the machine set just ten minutes at a time. The steam upon leaving the boiler under a pressure of 90 pounds would deliver about 350 degrees heat, but as it reaches the machine it expands and I doubt whether it would deliver more than 250 degrees at that point. We do not sterilize more than six inches in depth."

The method as described above used by Searles Brothers, Toledo, Ohio, appears not to attain actual soil sterilization. With essentially one crop, Grand Rapids lettuce, their practice has heretofore secured the results desired, and is accordingly satisfactory.

SUMMARY

1. It has been developed by the experience of greenhousemen in Ohio that continuous cropping inevitably leads to an accumulation of soil infesting disease organisms. These attack either the root or the above ground parts of the plants, and can be checked only through soil sterilization.

2. The plant beds or cold frames of truckers and gardeners utilized for growing seedling plants for outdoor use are similar in their sources of infection to greenhouses employed in continuous cropping. It is clear from experience reported by growers in the intensive trucking areas that some method of soil sterilization must be practiced.

3. In referring to intensive trucking, the authors have in mind the plant beds used to produce plants of tomato, cabbage, celery, cucumbers, and certain others. The seedling plants of tomatoes and cabbage are especially liable to become infected and to transmit very serious diseases to the soils in which they are grown.

4. Efficient sterilizing of seed bed soils will be required at least as often as once in two years; occasional sterilizing every year will be needed.

5. The particular method of sterilizing is of minor importance. Originally the perforated pipe method of steaming was most largely used. It has been replaced in the Cleveland district by the inverted pan method. In either case the steaming is carried on long enough to heat and sterilize the soil, at least one hour being required.

6. The formalin drench method of the strength of 3 or more pounds or pints of formaldehyde to 50 gallons of water, applied at the rate of one gallon per square foot of bed area, is effective, but is more expensive in the matter of actual cost for treatment, while less exacting in the matter of accessory devices for application.

The writers beg to acknowledge their obligations for assistance and courtesies rendered by growers and mechanics who have been consulted in the prep ıration of this circular.

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